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Sugarcane growth and yield responses to a 3-month summer flood

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ABSTRACT

Sugarcane (*Saccharum* spp.) in south Florida is often subjected to flooding due to interacting effects of soil subsidence, pumping restrictions, and tropical storms. While there has been considerable research on the response of sugarcane cultivars to high water tables and periodic flooding, there is a lack of information on commercial cultivar yield response to long-term flooding. An experiment was established in Belle Glade, FL to examine the effect of a 3-month summer flood (July–September) on the growth and yield of cultivars CP 80-1743 and CP 72-2086 during the plant cane (2003) and second ratoon (2005) crop. Harvest samples were taken early-, mid-, and late-season. Flooding sugarcane in the summer caused sequentially greater yield reductions throughout the harvest season in plant cane. Sucrose yields for flooded cane, compared with the non-flooded control, were 9.6 t sucrose ha^{-1} versus 11.7 t sucrose ha^{-1} early, 9.2 t sucrose ha^{-1} versus 12.8 t sucrose ha^{-1} mid-season and 7.8 t sucrose ha^{-1} versus 12.3 t sucrose ha^{-1} at late harvest. In the second ratoon crop, flooding reduced sugarcane tonnage and sucrose yield by 54–64% across sampling dates, and preliminary results indicated that flooding reduced leaf nutrient content by 10–78%. Yield reductions due to flooding in both crops were attributed more to reduced tonnage rather than sucrose content. CP 72-2086 yielded 18–28% greater sucrose than CP 80-1743 when harvested late. However the flood $\times$ cultivar interaction was not significant as both cultivars recorded similar yield reductions under flooded conditions. Our results identified severe yield losses caused by a 3-month summer flood in these cultivars, particularly in ratoon crops. Strategies to increase summer on-farm water storage in Florida should focus on short-duration periodic flooding rather than long-term flooding.

1. Introduction

Sugarcane (*Saccharum* spp.) is an important economic crop in the tropics and sub-tropics due to its high sucrose content and bioenergy potential. Sugarcane in south Florida is often subject to flooding during the summer. Florida sugarcane is grown primarily in the Everglades Agricultural Area, a 280,000 ha basin of Histosols drained for agricultural use. When drained, the high-organic matter soils are subject to microbial oxidation and soil subsidence at the rate of approximately 1.4 cm year^{-1} (Shih et al., 1998). As soils become shallower, each rainfall floods a greater percentage of the soil profile, making drainage more difficult. In addition, best management practices to reduce pumping and keep more water on-farm have been implemented to reduce P in farm water exported to the natural Everglades (Rice et al., 2002). Finally, south Florida is subject to flooding from tropical storms which may inundate sugarcane fields in the late summer and fall (Sartoris and Belcher, 1949).

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Floods, particularly if prolonged, have the ability to negatively affect sugarcane yields (Berning et al., 2000). There is evidence, however, of tolerance to high water tables and periodic flooding in Florida (Canal Point, ''CP'') sugarcane germplasm. Pitts et al. (1990) found that sucrose yields were not affected in CP 72-1210 when grown at water table depths of 45 and 75 cm. Glaz et al. (2002) recorded variability among commercial CP cultivars in tolerance to high water tables. CP 72-2086 was not affected while CP 80-1743 yields were reduced 25% in the high water-table treatment. They recommended screening of genotypes under high water tables. Glaz et al. (2002) reported a mean yield reduction of 8% in a wet field (average water table levels 13–17 cm below the soil surface) compared with a drier field (average water tables levels 29–39 cm below the soil surface). Glaz et al. (2004a) reported yield reductions of 18 and 28% in genotype CP 95-1376 when exposed to 7-day flood cycles (water 0–2.5 cm above the soil surface), whereas yields of genotype CP 95-1429 were not affected by the same 7-day floods. Additionally, Glaz et al. (2004b) found neutral or positive responses of sugarcane photosynthesis, transpiration and stomatal conductance to periodic 7-day floods. Glaz and Gilbert (2006) found that 2-day periodic floods increased cane and sucrose yields in plant cane crops of CP 72-2086 and CP 80-1827, and Chabot et al. (2002) reported that sugarcane transpiration rates were maintained under high water tables in cultivar CP 66-345.

While many studies have indicated that CP germplasm can tolerate high water tables and periodic floods, long-term flooding has been less studied, particularly for commercial cultivars, and yield losses appear to be greater. Sartoris and Belcher (1949) reported that CP sugarcane clones survived a 105-day flood following two tropical storms in 1947. Srinivasan and Batcha (1962) flooded 68 clones of *Saccharum* and related genera for 6 months. They found that *S. spontaneum* and *S. robustum* clones were flood tolerant but *S. officinarum* clones died when flooded. They also noted a significant reduction (magnitude not reported) in leaf area index (LAI) with flooding. Webster and Eavis (1972) noted a reduction in LAI of 25% in 1-month old sugarcane plants flooded for 14 or 30 days. Deren et al. (1991) screened 160 CP clones for flood tolerance to a 5-month flood during July–November. They found that several clones produced >70% sucrose yield in flooded compared with non-flooded conditions. They surmised that CP germplasm was inadvertently selected for flood tolerance due to repeated exposure to flooding in the history of the breeding program, and concluded flood tolerance was present in modern CP clones. Morris and Tai (2004) examined 12 sugarcane genotypes subjected to 0, 15 and 30 cm deep water tables for 8 months. Shoot dry weight of the 0 cm treatment was reduced compared with the 30 cm water table.

While there is reasonable evidence to indicate that some CP cultivars may tolerate high water tables and periodic flooding, there is a lack of information on commercial cultivar growth and yield under long-term floods of less duration than 5 months. We suspect that sugarcane cultivar tolerance and yield response to long-term flood may be different than high water tables due to increased anoxia in the root zone and associated morphological and nutrient uptake changes in the plant. Sugarcane yield response to long-term flood would be useful information for Florida growers since subsiding soils, increased restrictions on pumping, and increased frequency of tropical storms (Emmanuel, 2005; Klotzbach, 2006) have increased the incidence of flooding on their farms.

The objective or our study was to determine the effect of a 3-month summer flood on sugarcane growth and yield in two commercial cultivars, CP 72-2086 and CP 80-1743, known to have different tolerance to high water tables.

2. Materials and methods

2.1. Experimental design

The experiment was planted on 27 February 2003 at the University of Florida Everglades Research and Education Center (EREC; 26°39′N, 80°38′W) in Belle Glade, FL on a Lauderhill muck (euic, hyperthermic and Lithic Haplosaprist) soil. Fields formerly used for rice paddy experiments (Deren et al., 1991) were chosen because these fields were equipped to isolate floods hydrologically. The experiment was planted as a 2 × 2 factorial in a split-plot arrangement of a randomized complete block design with four replications, with water table as the main plot and cultivar the sub-plot. Each sub-plot was 15.2 m long × 4 rows wide, with 1.5-m between row spacing. The two cultivars used in this study, CP 72-2086 (tolerant) and CP 80-1743 (not tolerant), were chosen based on a previous report of their different tolerance to high water tables (Glaz et al., 2002). Water tables were maintained at either a target height of 15 cm above the soil surface (flooded), or at natural hydrological levels (non-flooded), which averaged from 11.2 to 18.4 cm below the soil surface (Table 1). The flood treatment was imposed from 1 July through 30 September each year, the period of greatest rainfall during which flooding is most likely to occur in the EAA. The flooded treatment was maintained by pumping water into the fields throughout the flood period. Boards were installed in drainage ditches at the field outlets to maintain water height at

Table 1 – Climatic variables and water table heights for the plant cane (2003) and second ratoon (2005) sugarcane crops at the Everglades Research and Education Center, Belle Glade, FL

Year	Average air temperature (°C)	Total precipitation (cm)	Water table height, July–September (flooded) (cm above soil surface)	Water table height, July–September (non-flooded) (cm above soil surface)
Plant cane				
2003	26.1	45.1	13.6	−11.2
Second ratoon				
2005	26.7	34.6	10.7	−18.4

approximately 15 cm during flooding. Results are reported for the plant cane crop in 2003 and the second ratoon crop in 2005. First ratoon crop results are not included because the rainfall of Hurricanes Frances and Jeanne in September 2004 flooded all treatments and thus made flood treatment comparisons impossible. While the 2004 hurricanes adversely affected the first ratoon crop, sugarcane plants recovered sufficiently after harvest to produce similar leaf area indices in all treatments prior to initiation of the second ratoon flood.

One water table logger (Model WL15, Global Water Instrumentation Inc., Gold River, CA)[1] equipped with a submersible pressure transducer was installed in the center of each main plot (flooded or drained). Installation consisted of inserting an access tube that was made from perforated PVC well-water pipe (5.1 cm diameter) through the muck soil to bedrock. The water table sensors were placed inside the access tubes until the bottom of the sensors touched the bedrock surface. Water table heights were recorded every 15 min and daily averages were calculated beginning 1 July and ending 30 September each year. Air temperatures were recorded every 15 min from sensors placed 2 m above the soil surface at the EREC weather station <1 km from the experimental site. Cumulative monthly rainfall totals were also calculated from daily rainfall totals recorded at the EREC weather station.

2.2. *Leaf area indices*

Sugarcane leaf area index (LAI) measurements were performed on 5 June, 7 July, 13 August and 9 September 2003 in the plant cane crop and 9 June and 13 July 2005 in the second ratoon crop. LAI equipment failure precluded measurements after 13 July 2005 in the second ratoon crop. Leaf area was measured non-destructively using a SunScan Canopy Analysis System (Dynamax Inc., Houston, TX). This system uses a 1-m wand placed beneath the crop canopy to measure transmitted photosynthetically active radiation (TPAR), and an unshaded beam fraction sensor is placed outside the plots to measure incident photosynthetically active radiation (IPAR). The two sensors are connected with a cable and simultaneous readings of TPAR and IPAR are taken, with the difference used to calculate LAI. In a comparison of non-destructive LAI measurement systems, SunScan recorded measurements of LAI similar to AccuPar and LAI-2000 (Wilhelm et al., 2000).

As the SunScan wand is 1.0 m and between-row sugarcane spacing is 1.5 m, it was necessary to take two measurements diagonally across the sugarcane row, spanning from mid-row to mid-row, and average these readings to obtain one LAI measurement. This procedure was repeated twice per plot to obtain two measurements of LAI which were then averaged for each plot. All LAI measurements were performed between 10:00 and 14:00.

2.3. *Leaf nutrient concentration*

Leaf nutrient concentration samples were taken from the second ratoon crop on 6 October 2005. Ten top visible dewlap leaves were harvested at random from the middle two rows of each plot. Leaf midribs were separated from leaf blades and discarded before washing the blades in deionized water and drying at 60 °C. The dried leaf material was ground to pass a 1 mm screen in a stainless steel Wiley mill. All ground samples were dried overnight at 65 °C before weighing for digestions. Total leaf N was determined by micro-Kjeldahl digestion on an aluminum digestion block and analysis with a flow analyzer. Leaf samples were also digested with nitric acid (2 h, 150 °C) followed by hydrogen peroxide (1 h, 150 °C) on an aluminum digestion block. Total P was determined by nitric acid/hydrogen peroxide digestion and analysis with the phosphomolybdate blue method (Murphy and Riley, 1962). Leaf K, Ca, Mg, Fe, Mn, Zn, and Cu concentrations were determined by atomic absorption spectrophotometry after the same digestion.

2.4. *Yield measurements*

Stalks from the middle two rows in each plot were counted in August of 2003 (plant cane), and 2005 (second ratoon). Samples to estimate stalk weight and sucrose content were collected three times during each crop cycle, 20 October 2003, 16 December 2003 and 9 February 2004 for plant cane and 4 October 2005, 17 January 2006 and 21 February 2006 for second ratoon. A 10-stalk random sample was used to estimate stalk weight. Plant fresh weights were used to determine individual stalk weight (kg stalk^{-1}), and tons of fresh biomass cane per hectare (TCH, t ha^{-1}) were calculated as the product of stalk number and stalk weight. To determine sucrose concentration (KST, kg sucrose t^{-1} cane), the 10-stalk samples were ground and the crusher juice analyzed for Brix and pol. Brix, which is a measure of percent soluble solids, was measured using a refractometer which automatically corrected for temperature. Pol, which is a unitless measure of the polarization of the sugar solution, was measured using a saccharimeter. Sucrose concentration was determined according to the theoretical recoverable sugar (TRS) method (Glaz et al., 2002), except that TRS values were multiplied by a coefficient of 0.863 to estimate commercially recoverable sucrose content (KST). Sucrose yield (TSH, t sucrose ha^{-1}) was calculated as the product of TCH and KST (divided by 1000 to convert kg sucrose to metric tonnes). All sugarcane in each plot was harvested mechanically in March of 2004 (plant cane) and 2005 (first ratoon), and the resultant regrowth measured as described above for the following ratoon crop.

2.5. *Statistical analyses*

Analyses of variance for all yield data were performed using PROC Mixed in SAS, with replications as random effects and crop, flood and cultivar as fixed effects. Since crop × flood interactions were significant for sugarcane yield traits, the data set was subsequently partitioned into separate yield sampling dates in each crop and re-analyzed with replications as random effects and flood and cultivar as fixed effects. Least squares means statements were used to determine probabilities of significant differences among treatment means for fixed effects (Littell et al., 2002). Significant differences are reported at $P = 0.05$ unless otherwise noted.

[1] Names of the products are included for the benefit of the reader and do not imply endorsement or preferential treatment by the University of Florida or USDA.

Table 2 – Analysis of variance F ratios and level of significance for leaf area index (LAI) measurements in the plant cane and second ratoon crops

Fixed effects	Plant cane				Second ratoon	
	5 June 2003	7 July 2003	13 August 2003	9 September 2003	9 June 2005	13 July 2005
Flood (F)	$0.04^{*,NS}$	1.42^{NS}	0.62^{NS}	11.2^{*}	4.17^{NS}	5.42^{NS}
Cultivar (Cl)	21.1^{**}	50.3^{***}	18.8^{**}	4.8^{NS}	3.7^{NS}	22.1^{**}
F × Cl	2.32^{NS}	0.01^{NS}	0.59^{NS}	0.00^{NS}	0.06^{NS}	3.72^{NS}

$^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

3. Results

3.1. Climate and water table levels

Water-table height above the soil surface during July–September in flooded treatments averaged 13.6 cm in plant cane and 10.7 cm in second ratoon, whereas the non-flooded treatment water table depth averaged 11.2 and 18.4 cm below the soil surface in plant cane and second ratoon, respectively, during the same time period (Table 1). Yearly average temperatures were similar between crops cycles, but the plant cane crop received 10.5 cm more rainfall.

3.2. Leaf area index

The effect of flood on LAI was significant only on the last sampling date in plant cane (9 September, Table 2). In contrast cultivar effects were significant for every sampling date except 9 September in plant cane. Early-season patterns of LAI in second ratoon were similar to plant cane as flood effects were not significant but cultivar effects were significant on the 13 July sampling date. The interaction of flood × cultivar was not significant for any LAI sampling date.

Flood and cultivar effects on sugarcane LAI had contrasting trends in the plant cane crop. Flooded and non-flooded sugarcane recorded similar LAI measurements more than 50 days after initiation of the flooded treatment (Fig. 1A). However, by the last sampling date in September, LAI was reduced by 1.1 units in the flooded treatment. In contrast, the LAI of CP 80-1743 was greater than CP 72-2086 for all sampling dates except September in plant cane (Fig. 1B). The difference in cultivar leaf development reflects the well-documented slow early-season growth of CP 72-2086, which has led to a late harvest season recommendation (Gilbert et al., 2004). The flood × cultivar interaction term was not significant indicating that LAI of both cultivars declined by 1.1 unit due to flooding on the 9 September sampling date (data not shown). In the second ratoon crop, the LAI of CP 80-1743 (5.0) was greater than that of CP 72-2086 (3.8) at the 13 July sampling date. By October, however, all flooded second ratoon plots exhibited markedly reduced plant height, and noticeable leaf yellowing. These effects were more noticeable in the second ratoon crop than the plant cane crop.

3.3. Leaf nutrient concentration

Since leaf nutrient concentration measurements were not repeated across crops, results reported should be regarded as preliminary. Leaf nutrient concentrations were affected by flooding in the second ratoon crop (Table 3). Flooding significantly reduced sugarcane leaf N, P, Ca, Mg, Zn and Cu, and trends toward lower K ($P = 0.08$), Fe ($P = 0.06$) and Mn ($P = 0.06$) were also observed. Percent reductions in leaf nutrient concentrations due to flooding ranged from 10% for

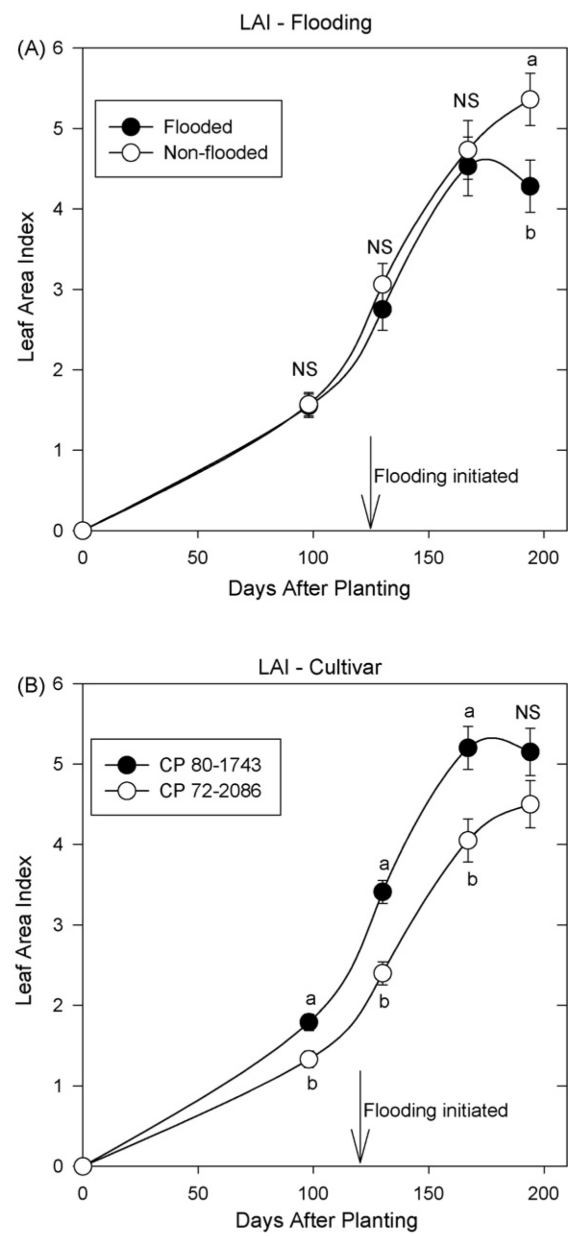

Fig. 1 – Sugarcane leaf area index (LAI) in the plant cane crop in response to (A) flood treatment and (B) cultivar.

Table 3 – Effect of a 3-month summer flood on sugarcane leaf nutrient concentrations in the second ratoon crop

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})
Flood	1.36	0.11	0.86	0.21	0.09	23.6	4.66	11.2	2.02
Non-flood	1.71	0.18	0.95	0.35	0.17	47.9	21.8	18.3	4.21
% Flood reduction[a]	20	39	10	40	47	51	78	39	52
P[b]	0.028	0.0029	0.083	0.032	0.004	0.062	0.056	0.012	0.003

[a] Defined as ((non-flood − flood)/non-flood) × 100.
[b] Probability level associated with difference between flood treatment means.

Table 4 – Analysis of variance F ratios and level of significance for overall yield data set analysis of sugarcane stalk number, stalk weight, sucrose concentration (KST), biomass yield (TCH) and sucrose yield (TSH)

Fixed effects	Stalk number	Stalk weight	KST	TCH	TSH
Crop (C)	5.68	137*,**	143**	30.3*	55.5**
Flood (F)	74.7**	85.7**	24.9*	171***	154**
Cultivar (Cl)	6.66*	14.8**	0.35	6.24*	2.86
C × F	53.5**	3.56	31.7*	13.4*	11.5*
C × Cl	1.52	1.09	34.3***	1.58	0.11
F × Cl	0.63	3.38	3.09	0.82	0.20
C × F × Cl	3.15	0.03	1.26	0.38	0.01

$^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

K to 78% for Mn (Table 3). Cultivar differences in Mg concentration were also noted with CP 72-2086 (0.15%) having greater Mg concentration than CP 80-1743 (0.11%). In addition there was a significant flood × cultivar interaction on Mn leaf concentration, with CP 72-2086 and CP 80-1743 having similar values when flooded (4.62 and 4.65 mg kg^{-1}), but CP 80-1743 (27.2 mg kg^{-1}) recording greater Mn concentration than CP 72-2086 (16.4 mg kg^{-1}) under non-flooded conditions. However, there were no other significant effects of cultivar or flood × cultivar on leaf nutrient concentration, indicating that the effect of flooding had a far greater impact on sugarcane plant nutrition than cultivar.

3.4. *Sugarcane yield traits*

Crop cycle (plant cane vs. second ratoon) significantly affected sugarcane stalk weight, KST, TCH and TSH (Table 4). A 3-month summer flood caused significant differences in all yield traits, and the crop × flood interaction was significant for sugarcane stalk number, KST, TCH, and TSH. Since the crop × flood interaction term was significant for all yield traits except stalk weight the data set was subsequently analyzed separately for each crop. The interactions of flood × cultivar or crop × flood × cultivar were not significant for any sugarcane yield trait.

The 3-month summer flood had significant effects on sugarcane stalk number (second ratoon), stalk weight (all sampling dates), sucrose concentration (late second ratoon only), biomass yield (all sampling dates) and sucrose yield (middle and late plant cane, early, middle and late second ratoon) (Table 5). Sugarcane plant population was reduced when flooded in second ratoon from 8.6 to 6.2 stalks m^{-2} (data not shown). Compared with the drained treatment, the 3-month summer flood reduced sugarcane stalk weight throughout the harvest season in both crop cycles (Fig. 2A and B). However, the magnitude of the reduction was greater in second ratoon (32–43%) than in plant cane (21–24%). In general, sucrose concentration was not affected by flooding. No differences in KST due to flooding were recorded in plant cane, and differences in KST became apparent only at the late sampling date in second ratoon (data not shown). The differences in final sucrose yields were due primarily to reduced tonnage rather than reduced sucrose content, and TCH and TSH showed similar trends within crops (Fig. 2C–F). Yield trends were different in plant cane and second ratoon crops. Yield losses associated with flooding in plant cane were more severe at late harvest dates. Sugarcane TCH was reduced 23% in October and 35% in February (Fig. 2C), and TSH was reduced 18% in October and 37% in February (Fig. 2E). In contrast, in the second ratoon crop sugarcane TCH was reduced 59% in October and 55% in February (Fig. 2D), and TSH was reduced 61% in October and 63% in February (Fig. 2F). The magnitude of the yield loss caused by flooding was greater in the second ratoon crop, which was more susceptible to flood stress than the plant cane crop.

There were significant differences between sugarcane cultivars (Table 5) in stalk number (plant cane), stalk weight (early and middle plant cane), sucrose concentration (early plant cane and late second ratoon), biomass yield (middle and late plant cane) and sucrose yield (late plant cane and late second ratoon). The interaction of flood × cultivar was not significant at any sampling date as yield reductions of both cultivars were similar under flood. Although the crop × cultivar interaction was not significant (Table 4), cultivar effects were more noticeable in the plant cane than second ratoon crops (Table 5). CP 72-2086 recorded greater stalk weights than CP 80-1743 at early and middle plant cane harvests (Fig. 3A), but stalk weights were not significantly different between cultivars in the second ratoon crop (Fig. 3B). In contrast, CP 80-1743 plant population (8.2 stalks m^{-2}) was greater than that of CP 72-2086 (7.7 stalks m^{-2}) in plant cane, but again no significant differences were noted between

Table 5 – Analysis of variance F ratios and level of significance for individual yield sampling analysis of sugarcane stalk number, stalk weight, sucrose concentration (KST), biomass yield (TCH) and sucrose yield (TSH)

Fixed effects	Stalk number	Stalk weight	KST	TCH	TSH
October 2003 (early plant cane)					
Flood (F)	1.14	15.5*	5.34	13.1*	7.94
Cultivar (Cl)	9.57*	12.2*	37.7***	1.46	4.35
F × Cl	0.64	3.91	3.35	3.48	0.00
December 2003 (middle plant cane)					
Flood (F)		16.1*	0.60	19.3*	17.0*
Cultivar (Cl)		6.9*	3.20	7.55*	4.4
F × Cl		0.07	1.67	0.27	0.00
February 2004 (late plant cane)					
Flood (F)		104**	2.30	53.0**	52.0**
Cultivar (Cl)		2.3	0.39	8.1*	7.9*
F × Cl		0.48	0.28	0.37	0.31
October 2005 (early second ratoon)					
Flood (F)	104***	124**	5.83	182***	124***
Cultivar (Cl)	0.73	1.50	1.66	0.42	0.01
F × Cl	2.67	3.56	1.79	0.68	0.01
January 2006 (middle second ratoon)					
Flood (F)		78**	6.6	234***	148***
Cultivar (Cl)		3.9	3.8	0.91	2.8
F × Cl		1.2	0.00	0.02	0.02
February 2006 (late second ratoon)					
Flood (F)		53**	36**	113**	69**
Cultivar (Cl)		2.8	34**	0.79	9.4*
F × Cl		0.22	0.15	0.03	0.92

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

cultivars in second ratoon (data not shown). Trends in sucrose concentration of the cultivars differed between crops (data not shown). In the plant cane crop, CP 80-1743 recorded greater KST (122 kg sucrose t^{-1}) than CP 72-2086 (103 kg sucrose t^{-1}) when harvested early, but KST samples from later harvest dates were not significantly different between cultivars. In the second ratoon crop, however, CP 72-2086 recorded greater KST (91 kg sucrose t^{-1}) than CP 80-1743 (77 kg sucrose t^{-1}) at the late harvest date in February, and early harvest samples were not significantly different. Thus, in plant cane superior biomass yield of CP 72-2086 late in the harvest season (Fig. 3C) led to an 18% greater sucrose yield than CP 80-1743 (Fig. 3E), whereas in the second ratoon crop increased sucrose concentration of CP 72-2806 late in the harvest season led to a 28% greater sucrose yield than CP 80-1743 (Fig. 3F). These results concur with the late harvest season recommendation for CP 72-2086 by Gilbert et al. (2004).

4. Discussion

Reduction in LAI with long-term flooding in this study concurs with previous research documenting a reduction in sugarcane leaf weight and/or area when flooded (Gilbert et al., 2007; Srinivasan and Batcha, 1962; Webster and Eavis, 1972). Flooding affected sugarcane plant growth by reducing stalk, leaf and primary root weight and stimulating adventitious root and aerenchyma development (Gilbert et al., 2007). In addition increased development of stalk cracks and stalk lodging was noted in flooded plots in this study.

Previous research indicated that CP 72-2086 is more tolerant of high water tables than CP 80-1743 (Glaz et al., 2002). However, in our study both cultivars recorded similar yield reductions under flooding. These results combined with previous studies show that there is a difference in sugarcane physiological response to water tables maintained beneath the soil surface and long-term flooding above the soil surface. In a study examining sugarcane morphological changes with flooding, Gilbert et al. (2007) found that long-term flooding of CP 72-2086 and CP 80-1743 led to reductions in primary root mass and length, decreased leaf weight, and increased adventitious root and aerenchyma development. Glaz et al. (2004a,b) surmised that constitutive formation of stalk aerenchyma may enable sugarcane to tolerate periodic floods. Despite the presence of stalk aerenchyma 50–75% up the stalk (Gilbert et al., 2007) neither cultivar was able to maintain yields when subjected to a 3-month summer flood. Long-term flooding causes prolonged anoxia in the root zone leading to greater stress than would be expected with high water tables. Reductions of 10–78% in flooded sugarcane leaf nutrient concentration of N, P, K, Ca, Mg, Fe, Mn, Zn and Cu recorded in this study indicate that decreases in sugarcane growth when flooded may have been due to reduced uptake of both macro- and micro-nutrients. Glaz and Gilbert (2006) reported that N fertilization did not affect sugarcane yields during repeated 2-day floods, evidence that flooding duration affects sugarcane nutrient uptake dynamics.

Flooding led to average yield losses of 3.4 t sucrose ha^{-1} in plant cane and 5.9 t sucrose ha^{-1} in second ratoon. Deren et al. (1991) recorded a plot mortality rate of 30–70% for diverse

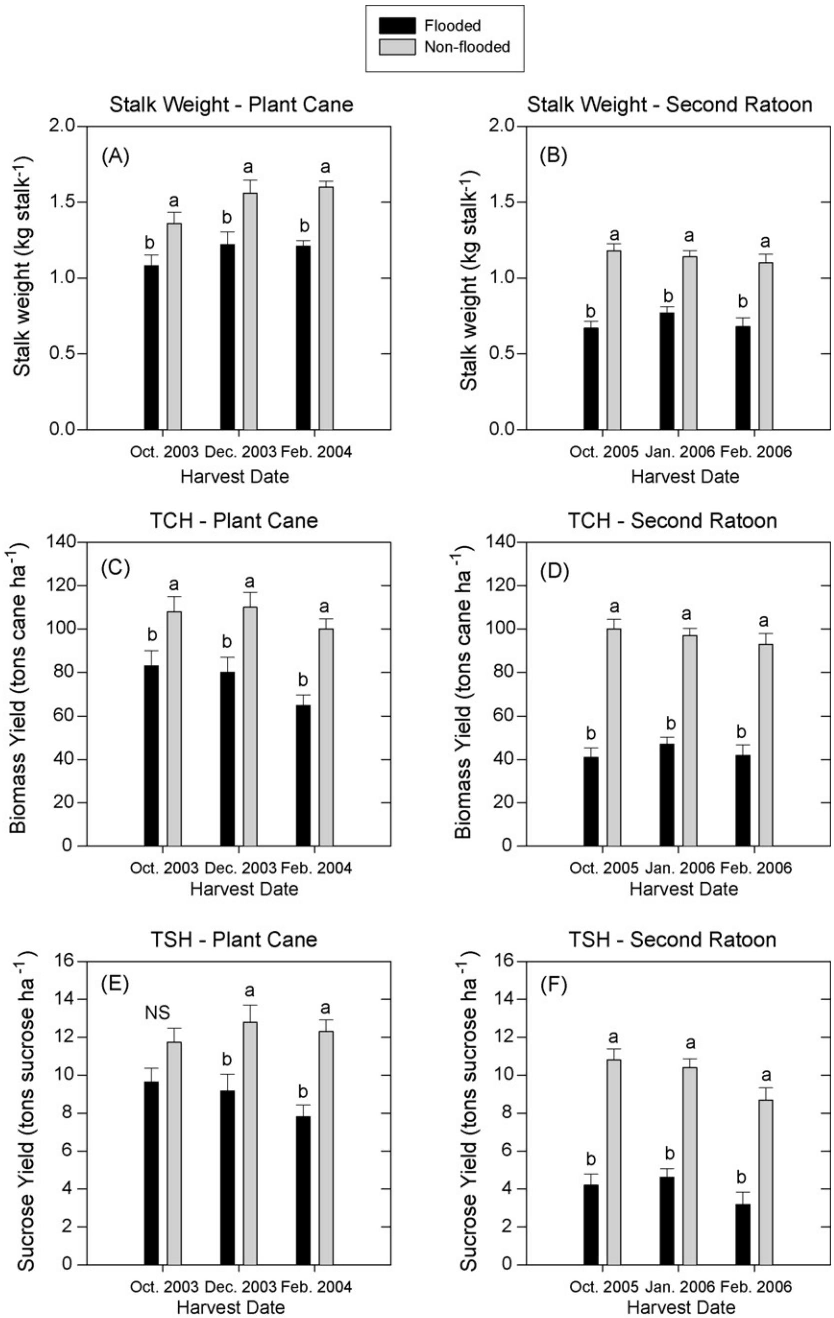

Fig. 2 – Effect of flooding on sugarcane (A and B) stalk weight, (C and D) biomass yield (TCH), and (E and F) sucrose yield (TSH) in the plant cane and second ratoon crops.

sugarcane germplasm flooded in the ratoon crop compared with 1–4% in plant cane. Thus our results concur with Deren et al. (1991) and indicate that the ratoon crop was more susceptible to flood stress than the plant cane crop.

Our sugarcane yield reductions of 18–37% in plant cane and 61–63% in second ratoon with a 3-month summer flood 11–14 cm above the soil surface are more severe than previous reports of 8% reduction with water tables 15 cm below the soil surface (Glaz et al., 2002), increased yields under a 2-day periodic flood (Glaz and Gilbert, 2006), and increased yields in a 45 cm versus 75 cm water table below the soil surface (Pitts et al., 1990). However, our yield reductions are comparable to the 40–50% average yield loss recorded by Deren et al. (1991) in a 5-month flood and the 47% reduction in shoot mass recorded by Morris and Tai (2004) in an 8-month flood. It is clear that long-term flooding has a greater effect on sugarcane yields than periodic flooding or high water tables, and that a 3-month flood causes severe yield losses, particularly in ratoon crops. Therefore, efforts to increase summer water storage on sugarcane farms should focus more on short-duration periodic flooding rather than long-term flooding. However, our LAI data and field observations suggest that flooding of durations less than 3 months may be less damaging. Future research should be conducted to

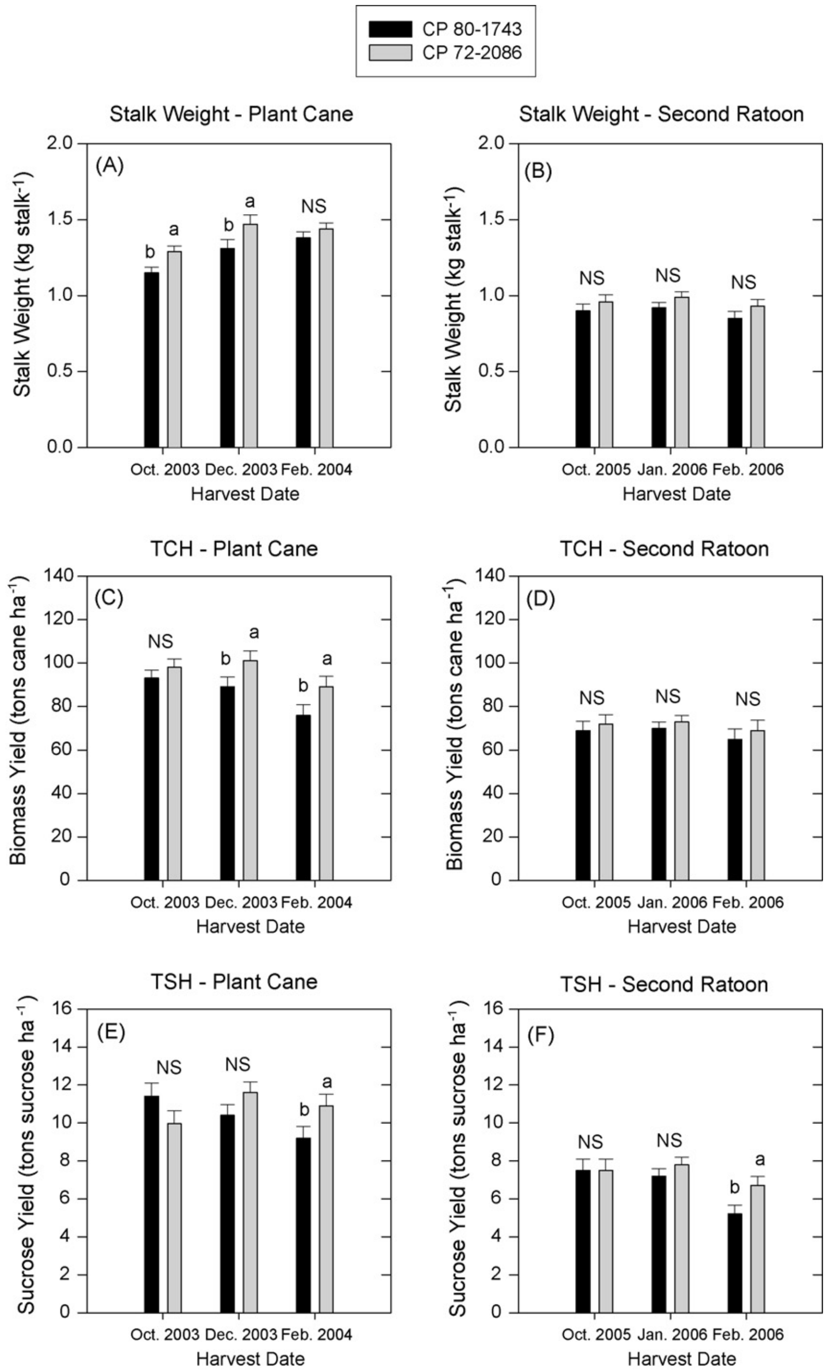

Fig. 3 – Effect of cultivar on sugarcane (A and B) stalk weight, (C and D) biomass yield (TCH), and (E and F) sucrose yield (TSH) in the plant cane and second ratoon crops.

determine the maximum length of flood tolerable for a range of CP germplasm.

5. Conclusion

Our study showed that two Canal Point sugarcane cultivars, with differing tolerance to high water tables, experienced yield losses of 18–37% in plant cane and 61–63% in second ratoon when subjected to a 3-month summer flood. Efforts to increase water storage on-farm to reduce soil subsidence or P export in Florida should focus on short-duration periodic flooding of sugarcane fields, as CP germplasm is more tolerant of high water tables or periodic (2–7 days) floods than long-term floods. Future research should be conducted to determine the maximum summer flood duration that would not reduce yields, likely between 7 days and 3 months, for CP sugarcane germplasm.

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